OPEN-FILE REPORT 98-16

SEISMIC HAZARD EVALUATION OF THE GLENDORA 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

1998

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

THE RESOURCES AGENCY	**STATE OF CALIFORNIA**	**DEPARTMENT OF CONSERVATION**
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DIVISION OF MINES AND GEOLOGY
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PREFACE

With the increasing public concern about the potential for destructive earthquakes in northern and southern California, the State Legislature passed the Seismic Hazards Mapping Act in 1990. The purpose of the Act is to protect the public from the effects of strong ground shaking, liquefaction, landslides or other ground failure, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act closely resemble those of the Alquist-Priolo Earthquake Fault Zoning Act (which addresses only surface fault-rupture hazards) and are outlined below:

1. **The State Geologist** is required to delineate the various "seismic hazard zones."

2. **Cities and Counties**, or other local permitting authorities, must regulate certain development "projects" within the zones. They must withhold the development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans.

3. **The State Mining and Geology Board (SMGB)** provides additional regulations, policies, and criteria to guide cities and counties in their implementation of the law. The SMGB also provides criteria for preparation of the Seismic Hazard Zone Maps (Web site http://www.consrv.ca.gov/dmg/shezp/zoneguid/) and for evaluating and mitigating seismic hazards.

4. **Sellers (and their agents)** of real property within a mapped hazard zone must disclose at the time of sale that the property lies within such a zone.

As stated above, the Act directs the State Geologist, through the Division of Mines and Geology (DMG) to delineate seismic hazard zones. Delineation of seismic hazard zones is conducted under criteria established by the Seismic Hazards Mapping Act Advisory Committee and its Working Groups and adopted by the California SMGB.

The Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Evaluation Reports, released as Open-File Reports (OFR), summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These Open-File Reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. Copies of the reports may be purchased at the Sacramento, Los Angeles, and San Francisco offices. In addition, the Sacramento office offers prepaid mail order sales for all DMG OFRs. **NOTE: The Open-File Reports are not available through BPS Reprographic Services.**

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Seismic Hazard Evaluation Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that the 1) process for zoning liquefaction hazards remain unchanged and that 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Evaluation Report summarizes the development of the hazard zone map for each area. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historic high-water-table information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Glendora 7.5-Minute Quadrangle (scale 1:24,000).

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Glendora 7.5-Minute Quadrangle, Los Angeles County, California

By
Ralph Loyd and Christopher J. Wills

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Glendora 7.5-minute Quadrangle (scale 1:24,000). This section and Section 2 addressing earthquake-induced landslides, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure has historically been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated granular sediments within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Glendora Quadrangle.

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils is generally confined to areas covered by Quaternary sedimentary deposits. Such areas consist mainly of alluviated valleys, floodplains, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth and thickness of liquefiable sediments, depth to ground water, rate of drainage, slope gradient, proximity to free-face conditions, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to determine the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction potential, opportunity, susceptibility, and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Glendora Quadrangle covers an area of about 62 square miles in eastern Los Angeles County. About 6 square miles in the southwestern quarter of the quadrangle is in the densely populated San Gabriel Valley. The remainder of the land in the quadrangle lies within the San Gabriel Mountains. Except for 7 or 8 square miles of private land along the mountain front, the rest of the mountainous terrain lies within Angeles National Forest. Parts of the cities of Glendora, San Dimas, and La Verne lie within the valley part of the quadrangle. Primary transportation routes in the quadrangle area are east-west in the San Gabriel Valley. These include the Foothill Freeway (I-210) and major thoroughfares such as Foothill Boulevard. A major access route into the San Gabriel Mountains, San Gabriel Canyon Road (State Highway 39) leads northward from Azusa on the adjacent Azusa Quadrangle and across the western part on the Glendora Quadrangle. A secondary route into the mountains, Glendora Ridge Road begins in Little Dalton Canyon, north of Glendora, climbs out of the canyon to the west, then follows the ridge to the north and east.

The San Gabriel Mountains rise very abruptly from the valley and reach elevations of about 3500 feet near the center of the quadrangle along the ridge followed by Glendora Ridge Road. The mountains are composed of a complex assemblage of Precambrian through Cretaceous igneous and metamorphic rocks that have been thrust to the south over the adjacent basins. Slopes in the crystalline bedrock are “exceptionally steep and insecure” (Muir, 1877), which, along with periodic torrential rains, leads to periodic debris flows and floods in the valley.

Streams draining the San Gabriel Mountains have deposited alluvial fans in the valley. The San Gabriel River, the largest stream in the mountains, drains a watershed of over 200 square miles. Along the western side of the Glendora Quadrangle, the San Gabriel River flows through a deep canyon, San Gabriel Canyon, now occupied by Morris Reservoir and San Gabriel Reservoir. North of San Gabriel Reservoir, the river splits into a west-flowing branch on the east and an east-flowing branch, called the West Fork, that drains an area in the adjacent Azusa Quadrangle. Other major drainages on the Glendora Quadrangle are Little Dalton canyon and Big Dalton Canyon, which end in Glendora, and San Dimas Canyon, which drains southward to the La Verne and San Dimas areas at the southeastern corner of the quadrangle. Of these drainages, only Big Dalton Canyon and Little Dalton Canyon, and the smaller nearby canyons have deposited substantial alluvial deposits in the Glendora Quadrangle. The resulting alluvial fans form the surface upon which the City of Glendora sits.

GEOLOGIC CONDITIONS

Surface Geology

In preparing the Quaternary geologic map for the Glendora Quadrangle, geologic maps prepared by Nourse and others (1998), Crook and others (1987), and McCalpin (unpublished) were referred to. We began with the maps of McCalpin (unpublished), and Nourse and others (1998) as files in the DMG Geographic Information System. Nourse and others (1998) mapped the mountainous areas of the quadrangle showing the bedrock geology in great detail. McCalpin mapped the Quaternary units, primarily using geomorphic expression and soil surveys to map and determine the ages of various Quaternary geologic units. He also incorporated the mapping of Crook and others (1987), especially for areas of artificial fill, which McCalpin had not mapped originally (McCalpin, personal communication, 1998). McCalpin's mapping also used the SCAMP nomenclature for geologic units (Morton and Kennedy, 1989). Nourse and others (1998) mapping of bedrock also showed the geologic boundaries between the bedrock and Quaternary units with more detail than McCalpin. The completed map of Quaternary geology uses primarily boundaries between the geologic units as mapped by Nourse and others (1998) in the mountainous areas and McCalpin in the valley, with unit designations modified somewhat from McCalpin based on Crook and others (1987). The Quaternary geologic map of the Glendora Quadrangle is reproduced as Plate 1.1.

The Quaternary geologic map (Plate 1.1) shows that the valley areas of the Glendora Quadrangle are covered by alluvial fans of various ages, including remnants of very old fans along the front of the San Gabriel Mountains, older alluvial surfaces, and young alluvial fans. The sources of the sediment that makes up the other young fans have been the small drainages, usually with only a few square miles of watershed, in the San Gabriel Mountains. The largest drainage in the area, in Big Dalton and Little Dalton canyons, has deposited a young alluvial fan beginning just south of the mountain front. The alluvial fans are composed primarily of sand, silt, and gravel, the compositions of which reflect the crystalline rocks of the San Gabriel Mountains. San Dimas Canyon, which is equivalent in size to Big and Little Dalton canyons, reaches the mountain front at the southern edge of the quadrangle, so sediments from this drainage area were deposited on the adjacent San Dimas Quadrangle. On the Glendora Quadrangle, the alluvial units have been subdivided into very old alluvium (Qvof), four generations of older alluvium (Qoa1 – Qoa4), four generations of young alluvium (Qya1- Qya4) and active wash and fan deposits (Table 1.1).

	Alluvial Fan Deposits	Alluvial Valley Deposits	Age
Active	Qf- active fan	Qa	
	Qw- active wash		
Young	Qyf4	Qya4	Holocene
	Qyf3	Qya3	
	Qyf2		
	Qyf, Qyf1	Qya, Qya1	
		Qoa3	
	Qof2	Qoa2	
Old	Qof, Qof1	Qoa, Qoa1	Pleistocene?
Very old	Qvof		Pleistocene

Some unit names include the "characteristic grain size" (e.g. Qyf2a, Qofg), b: boulder gravel, g: gravel, a: arenaceous (sand), s: silty, c: clayey.

Table 1.1. Units of the Southern California Areal Mapping Project (SCAMP) nomenclature used in the Glendora Quadrangle.

Subsurface Geology and Geotechnical Characteristics

No borehole logs were collected for the Glendora Quadrangle study because adequate hydrologic data (see Ground Water section) showed that almost all of the alluvial valley area covered by the quadrangle has been characterized by deep ground water levels throughout historical time. Since such areas do not contain soils susceptible to liquefaction, soil analyses is not required. Also, no borehole logs were located for the few canyon outlet areas identified as having historical shallow ground water levels. Zoning of areas lacking adequate subsurface data is accomplished using criteria adopted by the State Mining and Geology Board (see Criteria For Zoning section).

GROUND-WATER CONDITIONS

Liquefaction hazard mapping focuses on areas characterized by historical ground-water depths of 40 feet or less. Accordingly, a ground-water evaluation was performed in the Glendora Quadrangle to determine the presence and extent of historical shallow ground water. Data required to conduct the evaluation were obtained from technical publications, geotechnical boreholes, and water-well logs dating back to the turn-of-the- century, namely 1904 ground-water contour maps (Mendenhall, 1908), 1944 ground-water contour maps (California Department of Water Resources, 1966), shallow ground-water maps included in Leighton and Associates (1990), and ground-water level measurements reported in compiled 1960-1997 geotechnical and water-well borehole logs.

Shallow ground-water conditions (less than 40 feet depth) were identified in several areas within the Glendora Quadrangle (Plate 1.2). All three areas are situated along the northern margin of the San Gabriel Valley where near-surface sediments are frequently saturated by surface and subsurface waters flowing within and from Harrow, Englewild, Little Dalton, Big Dalton, and San Dimas canyons. Upon entering the valley, such water quickly descends to great depths through the porous sand and gravel deposits that dominate the valley sediments deposited along the base of the range front.

PART II

EVALUATING LIQUEFACTION POTENTIAL

Liquefaction occurs in water saturated sediments during moderate to great earthquakes. Liquefied sediments are characterized by a loss of strength and may fail, causing damage to buildings, bridges, and other such structures. A number of methods for mapping liquefaction hazard have been proposed; Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of susceptibility units, and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce liquefaction potential. Liquefaction susceptibility is a function of the capacity of sediments to resist liquefaction and liquefaction opportunity is a function of the seismic ground shaking intensity. The application of the Seed Simplified Procedure (Seed and Idriss, 1971) for evaluating liquefaction potential allows a quantitative characterization of susceptibility of geologic units. Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for mapping liquefaction hazards in the Los Angeles region. Following criteria adopted by the California State Mining and Geology Board (in press), the method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985), combining geotechnical data analyses, and geologic and hydrologic mapping, but follows criteria adopted by the California State Mining and Geology Board (in press).

LIQUEFACTION OPPORTUNITY

According to the criteria adopted by the California State Mining and Geology Board (in press), liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period. The earthquake magnitude is the magnitude that contributes most to the acceleration.

For the Glendora Quadrangle, a peak acceleration of 0.76 g resulting from an earthquake of magnitude 7.0 was used for liquefaction analyses. The PGA and magnitude values were derived from maps prepared by Petersen and others (1996) and Cramer and Petersen (1996), respectively. See the ground motion portion (Section 3) of this report for further details.

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of soils to loss of strength when subjected to ground shaking. Primarily, physical properties and conditions of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance. Soils that lack resistance (susceptible soils) are typically saturated, loose sandy sediments. Soils resistant to liquefaction include all soil types that are dry or sufficiently dense. Cohesive soils are generally not considered susceptible to liquefaction.

DMG’s map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil-property and soil-condition factors such as type, age, texture, color, and consistency, along with historic depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, findings can be related to the map units. DMG’s qualitative susceptible soil inventory is summarized on Table 1.2.

Quantitative Liquefaction Analysis

No quantitative analysis of liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and Harder, 1990, Youd and Idriss, 1997) was performed in the Glendora Quadrangle because no useful geotechnical borehole logs were available for areas having depths to ground water of 40 feet or less.

Map Unit	Age	Environment of Deposition	Primary Textures	General Consistency	Susceptible to Liquefaction?*
Qw	latest Holocene	active stream channels	sand, gravel, cobbles	very loose to loose	yes
Qf	latest Holocene	active alluvial fan deposits	sand, silt gravel	very loose to loose	yes
Qa	latest Holocene	active alluvial basin deposits	sand, silt, clay	very loose to loose	yes
Qyf1-4	Holocene to latest Pleistocene	younger alluvial fan deposits	gravel, sand, silt	loose to moderately dense	yes
Qya1-4	Holocene to latest Pleistocene	younger alluvial basin deposits	sand, silt, clay	loose to moderately dense	yes
Qof	late Pleistocene	older alluvial fan deposits	sand, gravel, silt, clay	dense to very dense	not likely
Qoa	late Pleistocene	older alluvial basin deposits	sand, silt, clay	dense to very dense	not likely
Qvof	Pleistocene	very old alluvial fan deposits	gravel, sand, silt, clay	dense to very dense	not likely

*** When saturated.**

Table 1.2. General geotechnical characteristics and liquefaction susceptibility of Quaternary sedimentary deposits in the Glendora Quadrangle.

LIQUEFACTION ZONES

Criteria for Zoning

The areas underlain by late Quaternary geologic units were included in liquefaction zones using the criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (in press). Under those criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historic earthquakes.

2. All areas of uncompacted fills containing liquefaction susceptible material that are saturated, nearly saturated, or may be expected to become saturated.

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable.

4. Areas where existing geotechnical data are insufficient**.**

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria for liquefaction zoning in the Glendora Quadrangle is summarized below.

Areas of Past Liquefaction

In the Glendora Quadrangle, no areas of documented historic liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported.

Artificial Fills

No artificial fill is mapped within the Glendora Quadrangle.

Areas with Existing Geotechnical Data

No areas within the Glendora Quadrangle were zoned on the basis of existing geotechnical borehole log data.

Areas without Existing Geotechnical Data

Areas within the Glendora Quadrangle that are characterized by near-surface, saturated younger Quaternary alluvium all lack geotechnical borehole log data. These areas, all of which are canyon bottoms and outlets (Harrow, Englewild, Big Dalton, Little Dalton, and San Dimas canyons), were zoned according to criteria 4a-c described above.

ACKNOWLEDGMENTS

The authors would like to thank the staff at the California Department of Transportation (Caltrans), the Southern District office of the California Department of Water Resources, and the Los Angeles Regional Water Quality Control Board for their assistance in the collection of subsurface borehole data. We thank James P. McCalpin for sharing his modern Quaternary mapping of the quadrangle and John Tinsley, U. S. Geological Survey, for facilitating access to digital copies of McCalpin's maps and providing boring log data. Special thanks to Bob Moskovitz, Teri McGuire, and Scott Shepherd of DMG for their GIS operations support and to Barbara Wanish for graphic layout and reproduction of Seismic Hazard Zone maps.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Glendora 7.5-Minute Quadrangle, Los Angeles County, California

By
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California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/index/htm).

This evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Glendora 7.5-minute Quadrangle (scale 1:24,000). This section and Section 1 addressing liquefaction, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Landslides triggered by earthquakes have historically been a major cause of earthquake damage. Landslides triggered by the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes were responsible for destroying or damaging numerous homes and other structures, blocking major transportation corridors, and damaging various types of life-line infrastructure. Typically, areas most susceptible to earthquake-induced landslides are on steep slopes and on or adjacent to existing landslide deposits, especially if the earth materials in these areas are composed of loose colluvial soils, or poorly cemented or highly fractured. These geologic and terrain conditions exist in many parts of southern California, most notably in hilly areas already developed or currently undergoing development. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region, which includes the Glendora Quadrangle.

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered primarily from a variety of outside sources; thus the quality of the data is variable. Although the selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Earthquake-generated ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. No attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Glendora Quadrangle, for more information on the delineation of liquefaction zones.

Information developed in the study is presented in two parts: physiographic, and geologic conditions in PART I, and ground shaking opportunity, landslide hazard potential and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Glendora Quadrangle covers an area of about 62 square miles in eastern Los Angeles County. About 6 square miles in the southwestern quarter of the quadrangle is in the densely populated San Gabriel Valley. The remainder of the land in the quadrangle lies within the San Gabriel Mountains. Except for 7 or 8 square miles of private land along the mountain front, the rest of the mountainous terrain lies within Angeles National Forest. Parts of the cities of Glendora, San Dimas, and La Verne lie within the valley part of the quadrangle. Primary transportation routes in the quadrangle area are east-west in the San Gabriel Valley. These include the Foothill Freeway (I-210) and major thoroughfares such as Foothill Boulevard. A major access route into the San Gabriel Mountains, San Gabriel Canyon Road (State Highway 39) leads northward from Azusa on the adjacent Azusa Quadrangle and across the western part on the Glendora Quadrangle. A secondary route into the mountains, Glendora Ridge Road begins in Little Dalton Canyon, north of Glendora, climbs out of the canyon to the west, then follows the ridge to the north and east.

The San Gabriel Mountains rise very abruptly from the valley and reach elevations of about 3500 feet near the center of the quadrangle along the ridge followed by Glendora Ridge Road. The mountains are composed of a complex assemblage of Precambrian through Cretaceous igneous and metamorphic rocks that have been thrust to the south over the adjacent basins. Slopes in the crystalline bedrock are “exceptionally steep and insecure” (Muir, 1877), which, along with periodic torrential rains, leads to periodic debris flows and floods in the valley.

Streams draining from the San Gabriel Mountains have deposited alluvial fans in the valley. The San Gabriel River, the largest stream in the mountains, drains a watershed of over 200 square miles. Along the western side of the Glendora Quadrangle, the San Gabriel River flows through a deep canyon, San Gabriel Canyon, now occupied by Morris Reservoir and San Gabriel Reservoir. North of San Gabriel Reservoir, the river splits into a west-flowing branch on the east and an east-flowing branch, called the West Fork, that drains an area in the adjacent Azusa Quadrangle. Other major drainages on the Glendora Quadrangle are Little Dalton canyon and Big Dalton Canyon, which end in Glendora, and San Dimas Canyon, which drains southward to the La Verne and San Dimas areas at the southeastern corner of the quadrangle. Of these drainages, only Big Dalton Canyon and Little Dalton Canyon, and the smaller nearby canyons have deposited substantial alluvial deposits in the Glendora Quadrangle. The resulting alluvial fans form the surface upon which the City of Glendora sits.

Residential and commercial development is concentrated in the gently sloping valley area. Hillside residential development began before World War II with small developments of single homes or cabins along streams at the base of the San Gabriel Mountains. Hillside development has continued with small residential developments along the mountain front and mass grading projects on the lower hills in the eastern part of the quadrangle.

The Seismic Hazard Zone Map for this quadrangle has been trimmed back so that it covers essentially only the south half of the Glendora 7.5-minute Quadrangle. The north boundary of the Zone Map is located one to two miles north of the Angeles National Forest Boundary along the San Gabriel Mountain front. The land excluded from the Zone map is National Forest land with only a few scattered inholdings of private property.

GEOLOGIC CONDITIONS

Surface and Bedrock Geology

Recently compiled geologic maps were obtained in digital form from the Southern California Areal Mapping Project (SCAMP). These maps include the Quaternary geologic map of McCalpin (unpublished) for the Glendora Quadrangle and the geologic map of Nourse and others (1998). These maps were compared with other geologic maps of the area by Shelton (1955), Streitz (1966), and Crook and others (1987). This mapping was briefly field checked; observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

The San Gabriel Mountains that cover most of the quadrangle are comprised of blocks of plutonic igneous and metamorphic rocks that are being thrust over the San Gabriel Valley from the north. Bedrock geology in the crystalline bedrock of the San Gabriel Mountains shown by McCalpin (unpublished) is simplified to just one unit, herein called Mx (Mesozoic crystalline rocks). More detail is shown in the southern part of the mountains east of Glendora where Miocene age volcanic rocks (Glendora Volcanics) and sedimentary rocks (Puente and Topanga formations) crop out. Nourse and others (1998) mapped the mountainous areas of the quadrangle, showing the bedrock geology in great detail, and also showing the locations of contacts between crystalline rocks and Quaternary sediments. The map by Nourse and others (1998) separates the crystalline bedrock of the San Gabriel Mountains into units based on age (i.e., Cretaceous, pre-Cambrian, etc.), gross rock type (i.e., granite, granodiorite,etc.), and accessory minerology (i.e., pyroxene-biotite granodiorite, hornblende-biotite granodiorite, etc.). This map also shows various suites of dikes of different mineralogies. The crystalline bedrock of the San Gabriel Mountains was considered as one strength group for slope stability analyses, and therefore, the detail provided in this map was more than that required for the evaluation of landslide susceptibility. Consequently, the map was simplified by grouping similar rock types together, and by including small isolated units with the larger surrounding rock units. For instance, granodiorites and quartz diorites of similar ages were grouped together, regardless of differences in accessory mineralogy, and shown as one unit on the final geologic map. If small dikes or inclusions of different rock were present within the granodiorite unit, they were also shown as part of the granodiorite unit. In order to show geologic contacts as accurately as possible, the final geologic map used for this evaluation used the simplified geologic boundaries from the mapping by Nourse and others (1998) in the mountainous areas, and those of McCalpin in the alluvial valley areas.

Major crystalline bedrock units mapped by Nourse and others (1998) in the Glendora Quadrangle include Precambrian granite (pCgr), granodiorite (pCgd), and gneissic rocks (pCgn). These are intruded by Triassic quartz monzonite, quartz diorite, and diorite, and Jurassic granite, designated as TRJgr, TRJgd, and TRJd on the final map. This suite of crystalline rocks is then intruded by Cretaceous granite, granodiorite, monzonite, quartz diorite, and diorite, designated as Kgr and Kgd on the final map. The metamorphic and plutonic rocks are cut by dikes and sills of late Jurassic or Cretaceous granite and Tertiary rhyolitic and mafic rock, however, as explained above, these dikes were not shown on the final geologic map. There are a few areas of undifferentiated bedrock shown on the final geologic map as "bedrock complex" (bc) or "metasedimentary" (ms) rock units.

In the nothern part of the quadrangle, zones of weakened, sheared rock are associated with the Vincent Thrust fault, or the more recent San Gabriel fault. Mylonitized gneiss (KTmy) is associated with the Vincent Thrust, and sheared rock units (shear zone) are discontinuously located along the San Gabriel fault.

Volcanic and sedimentary rocks of Miocene age overlie the metamorphic and intrusive rocks in the southern part of the quadrangle are. These include various units of the Glendora Volcanics, the Topanga Formation, and the Puente Formation. The Glendora Volcanics are a heterogeneous mixture of brecciated andesite flows (Tga), fine-grained andesite (Tgf), basalt (Tgb), tuff-breccia (Tgt), and undifferentiated volcanics (Tgv). The Topanga Formation (Tt) consists of bedded fine-grained marine sandstone and siltstone, with occassional interbeds of weak claystone. The Puente Formation (Tp) consists of bedded marine sandstone and diatomaceous shale, with local areas of interbedded, landslide-prone bentonite-clay shale.

Surficial units in the mountainous areas include colluvium (Qc), talus, and stream deposits in the canyons. Stream deposits are typically sand and gravel in the active channel (Qw), and raised terraces (Qt) capped by young alluvium (Qyf2) and older alluvium (Qoa1) above the modern channel level.

The valley areas of the Glendora Quadrangle are covered by alluvial fans of various ages (Qyf3a, Qyf3g, Qyf4a, Qyf4b, Qyf4g, Qof, Qofa, Qofs, Qof2a, Qof2g, including remnants of very old fans along the front of the San Gabriel Mountains (Qvofg), older alluvial surfaces (Qo, Qoa, Qoag, Qoa2g, Qoa3g), and younger fans (Qyf, Qyfa, Qyfg) and alluvial surfaces (Qaa, Qal, Qya, Qyaa, Qyab, Qyag, Qya1g, Qya3b, Qya3g, Qya4g). Other Quaternary units in the valley areas include colluvial deposits (Qycc, Qycg), active channel deposits (Qw, Qwa, Qwb, Qwg), and areas of artificial fill (Qaf, af). A more detailed discussion of the Quaternary deposits in the Glendora Quadrangle can be found in Section 1.

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, they must first be ranked on the basis of their overall shear strength. The primary source for rock shear-strength measurements is geotechnical reports prepared by consultants. These were obtained from the files of local government permitting departments. Shear strength data for the rock units identified on the geologic map were obtained from the Los Angeles County Public Works Department and the City of Glendora (see Appendix A).

Shear strength information was scarce or entirely lacking for some rock units in the Glendora Quadrangle. Where appropriate, strength data from adjacent quadrangles were used to characterize the shear strength of rock units within the quadrangle. The use of the data was considered appropriate where the rock units were similar in lithology, and were located within one half mile of the Glendora Quadrangle. Four shear strength tests from the Mount Baldy Quadrangle, and two from the San Dimas Quadrangle were used to supplement data from the Glendora Quadrangle.

The locations of rock and soil samples taken for shear testing within the Glendora Quadrangle, and those used to provide supplemental data from the adjacent San Dimas and Mount Baldy Quadrangles, are shown on Plate 2.1

Shear strength data gathered from the above sources were compiled for each mapped geologic unit, and subdivided for fine-grained and coarse-grained lithologies, if appropriate. Geologic units were grouped on the basis of average angle of internal friction (average f) and lithologic character. Geologic formations that had little or no shear test information were added to existing groups on the basis of lithologic and stratigraphic similarities.

To subdivide mapped geologic formations that have both fine-grained and coarse-grained lithologies, we assumed that where stratigraphic bedding dips into a slope (favorable bedding) the coarse-grained material strength dominates, and where bedding dips out of a slope (adverse bedding) the fine-grained material strength dominates. We then used structural information from the geologic map (see "Structural Geology") and terrain data in the form of slope gradient and aspect, to identify areas with a high potential for containing adverse bedding conditions. These areas, located on the map, were then used to modify the geologic material-strength map to reflect the anticipated lower shear strength for the fine-grained materials. In the Glendora Quadrangle, only the Topanga and the Puente Formations were analyzed for dip slope conditions.

The crystalline rocks of the San Gabriel Mountains have undergone repeated tectonic movement and compression, resulting in a pervasive fracturing, which imparts a common strength characteristic to all the rock units, which dominates other characteristics related to age and mineralogy. Based on shear test results obtained for Glendora and nearby quadrangles, and on phi values for similar rock types published in rock mechanics text books (Franklin and Dusseault, 1989; Hoek and Bray, 1981; and Jumikis, 1983), all the crystalline rocks of the San Gabriel Mountains were grouped into one strength group, designated "gr", for the landslide evaluation for the Glendora Quadrangle.

Existing landslides (Qls) were assigned a phi of 14 degrees for stability analysis calculations for this quadrangle. None of the geotechnical reports reviewed for the quadrangle contained any direct shear tests run on actual slide plane material, but there were a few such test results for nearby quadrangles. The phi values for slide plane material actually tested had a wide range, and 14 degrees was near the low end of this range. In those geotechnical reports that provided slope stability calculations, conservative assumed phi values were generally chosen, and 14 degrees was again on the low end of the range of values used. The results of the grouping of geologic materials in the Glendora Quadrangle are in Table 2.1 and Table 2.2

GLENDORA QUADRANGLE
SHEAR STRENGTH GROUPS

	Formation Name	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP A	gr*	12	38.5/37.5	38.5/37.5	156/178		38
GROUP B	Tgv*	16	33.5/35	33.7/34	294/300	Tp-fbc	34
	Qa*	46	33.7/34.5				
	Tt-fbc	4	34.3/33.5				
GROUP C		0		27	500	Tp-abc,Tt-abc, Ktmy/shear zone	27
GROUP D	Qls	0		14	400		14**

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength
gr* = stands for all pre-Tertiary crystalline units
Tgv* = includes Tga, Tgb, Tgf, Tgt, Tgv - Glendora Volcanics
Qa* = stands for af (fill) and all Quaternary units
** = phi value was assumed to be representative for existing landslides

Table 2.1. Summary of the Shear Strength Statistics for the Glendora Quadrangle.

SHEAR STRENGTH GROUPS FOR THE GLENDORA QUADRANGLE

GROUP A	GROUP B	GROUP C	GROUP D
pCgr	Tga	Tt-abc	Qls
pCgd	Tgb	Tp-abc	
pCgn	Tgf	Ktmy/shear zone	
TRJgr	Tgt		
TRJgd	Tgv		
TRJd	Tt-fbc		
Kgr	Tp-fbc		
Kgd	af & Qaf		
bc	Qyf,Qyfa, Qyfg		
ms	Qyf2, Qyf3a, Qyf3g		
	Qyf4a, Qyf4b, Qyf4g		
	Qof, Qofa, Qofs		
	Qof2a, Qof2g		
	Qvofg		
	Qaa, Qal, Qya		

Table 2.2. Summary of the Shear Strength Groups for the Glendora Quadrangle.

Structural Geology

Structural geologic information, including bedding and foliation attitudes (strike and dip) and fold axes, provided on geologic maps by Morton (1973) and Shelton (1955), along with field checking of rock units, were used to determine which rock units might display adverse bedding conditions. The crystalline rocks of the San Gabriel Mountains are massive to moderately foliated, with no obvious pattern of change in slope stability conditions related to changes in foliation attitude. Therefore, dip slope analysis was not performed on crystalline bedrock of the San Gabriel Mountains. Likewise, rock units of the Glendora Volcanics are not suited to dip slope analysis, because the structure is generally chaotic, owing to the heterogeneous nature of original emplacement, and to subsequent faulting and landsliding in the area adjacent to the Sierra Madre fault zone along the San Gabriel Mountain front. The two bedded marine units present in the quadrangle, the Topanga and the Puente Formations, did display alternating weak and strong layers, with lateral continuity of layering, that warranted dip slope analysis. We used the structural geologic information provided on the geologic map of Shelton (1955) to categorize areas of common stratigraphic dip direction and magnitude, similar to the method presented by Brabb (1983). The dip direction category was compared to the slope aspect (direction) category and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, and the bedding dip was greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area. This information was then used to subdivide mapped geologic units into areas where fine-grained and coarse-grained strengths would be used.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete picture of the previous occurrence of landsliding. An inventory of existing landslides in the Glendora Quadrangle was prepared (Treiman, 1998, unpublished) by combining field observations, analysis of aerial photos, and interpretation of landforms on current and older topographic maps. Aerial photos taken by the U.S. Department of Agriculture (1952/53) were the primary source for landslide interpretation. Also consulted during the mapping process were previous maps and reports that contain geologic and landslide data (Morton and Streitz, 1969; Streitz 1966; Crook and others, 1987). The completed hand-drawn landslide map was scanned and digitized by the Southern California Areal Mapping Project (SCAMP) at U.C. Riverside. A landslide database was attributed with information on confidence of interpretation (definite, probable, or questionable) and other properties, such as activity, thickness, and associated geologic unit(s). All landslides on the digital geologic map (from Nourse and others, 1998) were verified or re-mapped during preparation of the inventory map. To keep the landslide inventory of consistent quality, all landslides originally depicted on the digitized geologic map were deleted, and only those included in the DMG inventory were incorporated into the hazard-evaluation process. A version of this landslide inventory is included with Plate 2.1.

PART II

EARTHQUAKE-INDUCED LANDSLIDE GROUND SHAKING OPPORTUNITY

Design Strong-Motion Record

The Newmark analysis used in delineating the earthquake-induced landslide zones requires the selection of a design earthquake strong-motion record. For the Glendora Quadrangle, the selection was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996; Cramer and Petersen, 1996). The parameters used in the record selection are:

Modal Magnitude:	7.0 to 7.4
Modal Distance:	2.5 to 7.0 km
PGA:	0.63 to 0.74 g

The strong-motion record selected was the Channel 3 (north horizontal component) Pacoima-Kagel Canyon Fire Station recording from the magnitude 6.7 Northridge earthquake (Shakal and others, 1994). This record had a source to recording site distance of 2.6 km and a PGA of 0.44 g. The parameters associated with this record are lower than those shown above from the probabilistic ground motion maps. However, it was felt that the selected record better represented the expected ground motion at the southerly, more populated portion of the quadrangle. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

To develop a relationship between the yield acceleration (a_y; defined as the horizontal ground acceleration required to cause the factor of safety to equal 1.0) and Newmark displacements, the design strong-motion record was integrated twice for a given a_y to find the corresponding displacement, and the process repeated for a range of a_y (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for any combination of geologic material strength and slope angle, as represented by the yield acceleration. We used displacements of 30, 15 and 5 cm as criteria for rating levels of earthquake shaking damage on the basis of the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.074, 0.13 and 0.21 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant to the Glendora Quadrangle.

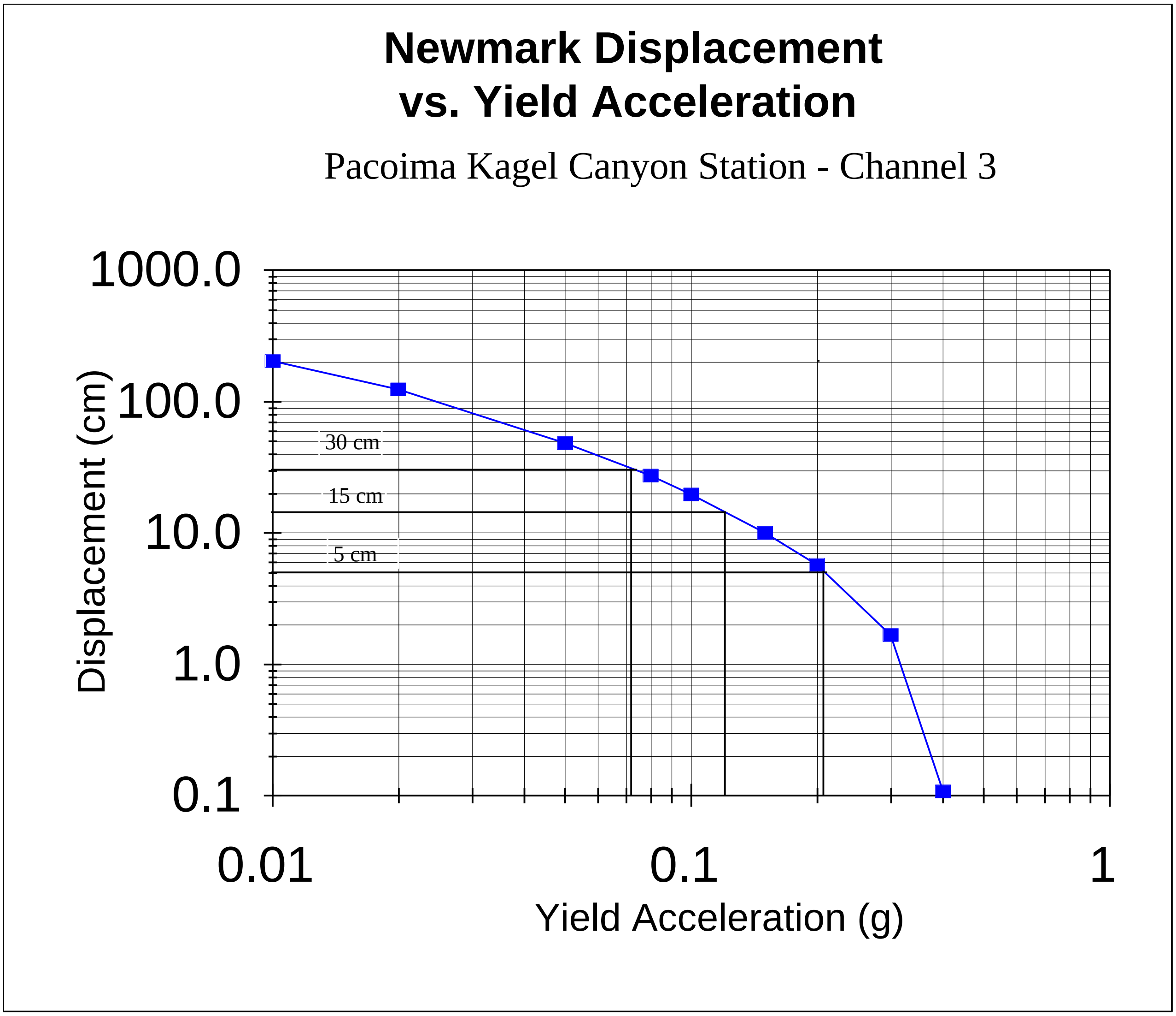

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Pacoima-Kagel Canyon Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake. Record from California Strong Motion Instrumentation Program (CSMIP) Station 24088.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. To calculate slope gradient for the terrain within the Glendora

Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle contours, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy. Surrounding quadrangle DEMs were merged with the Glendora DEM to avoid the loss of data at the quadrangle edges when the slope calculations were performed. A peak and pit smoothing process was then performed to remove errors in the elevation points.

To update the topographic base map, areas that have undergone large-scale grading as a part of residential development in the hilly portions of the Glendora Quadrangle were identified. Using 1:40,000-scale NAPP photography taken in June, 1994, and October 1995, photogrammetric DEMs covering the graded areas were prepared by the U.S. Bureau of Reclamation with ground control obtained by DMG. The photogrammetric DEMs were then merged into the USGS DEM, replacing the areas of out-dated elevation data.

A slope-gradient map was made from the combined DEMs using a third-order, finite difference, center-weighted algorithm (Horn, 1981). This map was used in conjunction with the geologic strength map in preparation of the earthquake-induced landslide hazard potential map.

Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield acceleration calculated by Newmark's equation represents the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. The acceleration values were compared with the ground shaking opportunity, defined by Figure 2.1, to determine the earthquake-induced landslide hazard potential. Based on the criteria described in Figure 2.1 above, if the calculated yield acceleration was less than 0.074g, expected displacements could be greater than 30cm, and a HIGH (H on Table 2.3) hazard potential was assigned. Likewise, if the calculated a_y fell between 0.074 and 0.13g a MODERATE (M on Table 2.3) hazard potential was assigned, between 0.13 and 0.21g a LOW (L on Table 2.3) potential was assigned, and if a_y were greater than 0.21g a VERY LOW (VL on Table 2.3) potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

GLENDORA QUADRANGLE
HAZARD POTENTIAL MATRIX

SLOPE CATEGORY

Geologic Material Group	MEAN PHI	I 0 - 18%	II 18 - 29%	III 29 - 37%	IV 37 - 44%	V 44 - 52%	VI 52 - 54%	VII 54 - 59%	VIII 59 - 63%	IX 63 - 69%	X > 69%
1	38	VL	VL	VL	VL	VL	VL	L	L	M	H
2	34	VL	VL	VL	VL	L	M	M	H	H	H
3	27	VL	VL	L	M	H	H	H	H	H	H
4	14	L-M	H	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Glendora Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone.

EARTHQUAKE-INDUCED LANDSLIDE ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (in press). Under those criteria, earthquake-induced landslide zones are areas meeting one or more of the following:

1. Areas known to have experienced earthquake-induced slope failure during historic earthquakes.

2. Areas identified as having past landslide movement, including both landslide deposits and source areas.

3. Areas where CDMG's analyses of geologic and geotechnical data indicate that the geologic materials are susceptible to earthquake-induced slope failure.

Existing Landslides

Studies of the types of landslides caused by earthquakes (Keefer, 1984) show that re-activation of the whole mass of deep-seated landslide deposits is rare. However, it has been observed that the steep scarps and toe areas of existing landslides, which formed as a result of previous landslide movement, are particularly susceptible to earthquake-induced slope failure. In addition, because they have been disrupted during landslide movement, landslide deposits are inferred to be weaker than coherent, undisturbed, adjacent source rocks. Finally, we felt that a long duration, San Andreas fault-type earthquake could be capable of initiating renewed movement in existing deep-seated landslide deposits. Therefore, all existing landslides identified in the inventory with a definite or probable confidence of interpretation were included in the hazard zone.

Minor rockfalls from steep roadcuts along the Glendora Ridge Road were triggered by the 5.5ML Upland earthquake of February 28. 1990. They were especially common in the vicinity of Horse Canyon Saddle near the center of the quadrangle (Allan Barrows, personal communication, 1998)

Geologic and Geotechnical Analysis

On the basis of a DMG pilot study (McCrink and Real, 1996) the earthquake-induced landslide zone includes all areas determined to lie within the High, Moderate and Low levels of hazard potential. Therefore, as shown in Table 2.3, geologic strength group 4 is always included in the zone (mapped landslides); strength group 3 materials are included in the zone for all slope gradients above 29 %; strength group 2 materials are included in the zone for all slope gradients above 44 %; and strength group 1 materials, the strongest rock types, are zoned for slope gradients above 54 %.

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APPENDIX A
SOURCES OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Glendora, Engineering Div. of Public Works	**41**
Los Angeles County Public Works Department	**37**
Total number of tests used to characterize the units in the Glendora Quadrangle	**78**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Glendora 7.5-Minute Quadrangle, Los Angeles County, California

By

Mark D. Petersen, Chris H. Cramer, Geoffrey A. Faneros, Charles R. Real and Michael S. Reichle

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included, are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5- minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple

Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California State Mining and Geology Board, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2, addressing liquefaction and earthquake-induced landslide hazards, constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the seismogenic sources as published in the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

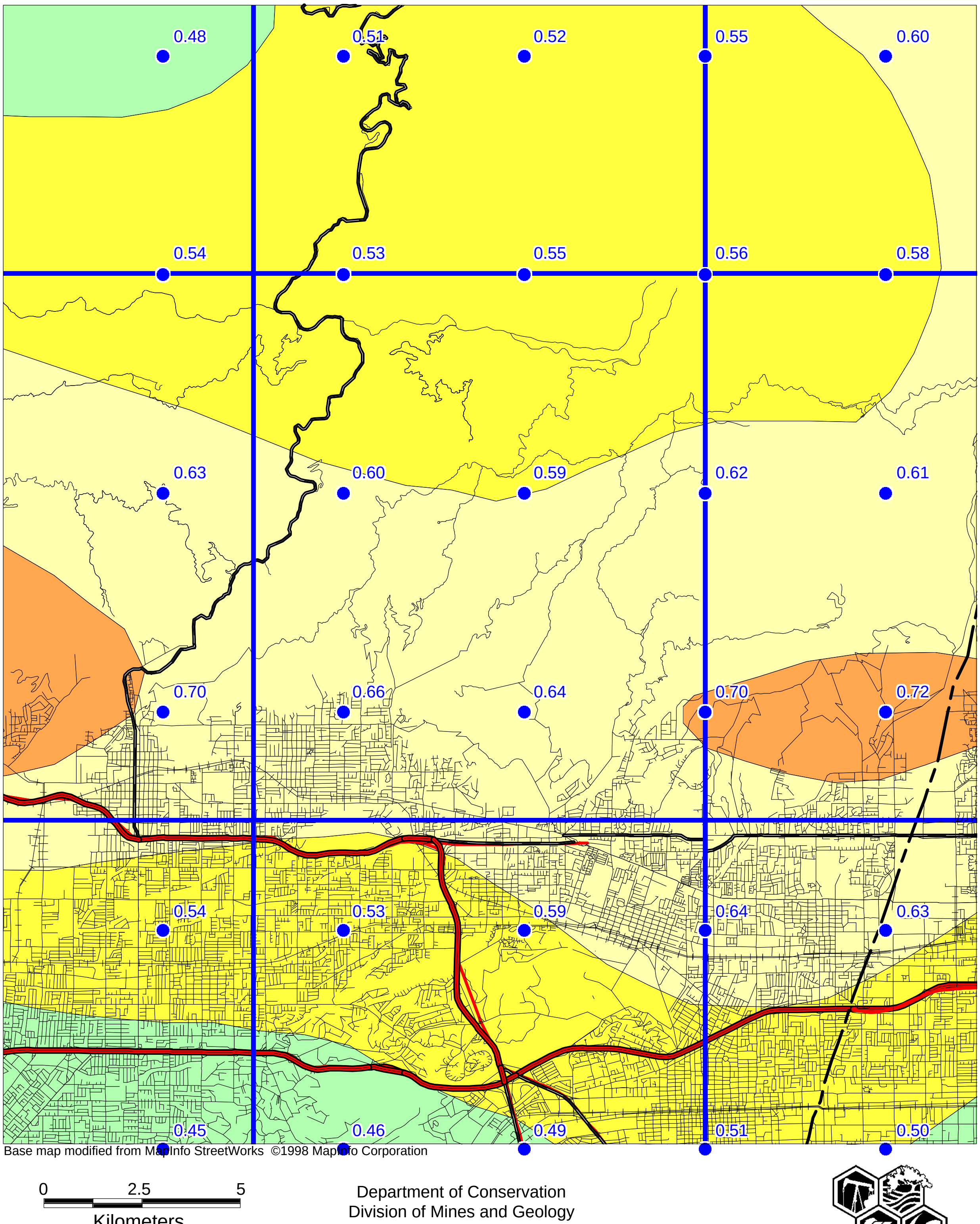
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

GLENDORA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Department of Conservation
Division of Mines and Geology

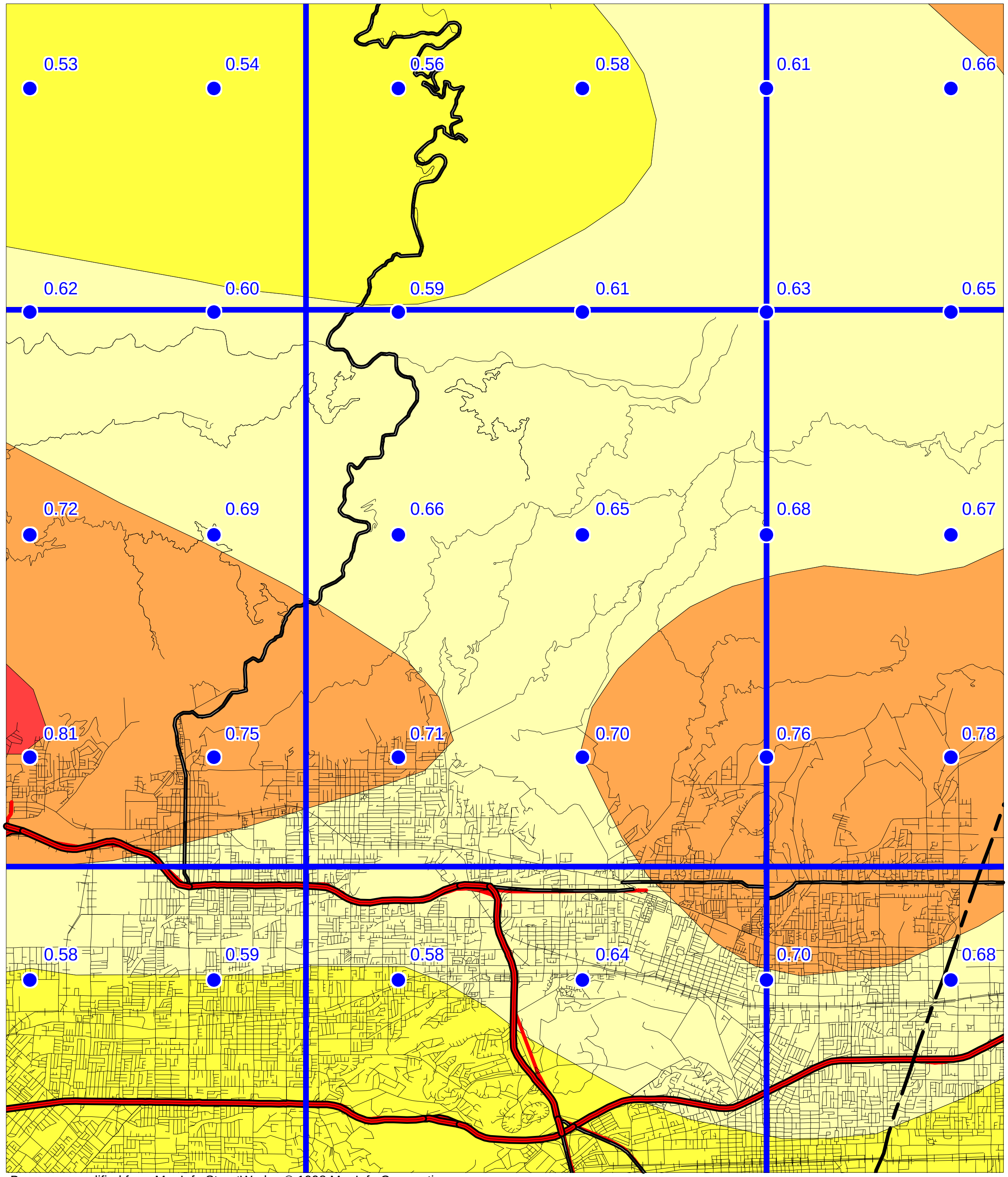
Figure 3.1

GLENDORA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 2.5 5
Kilometers

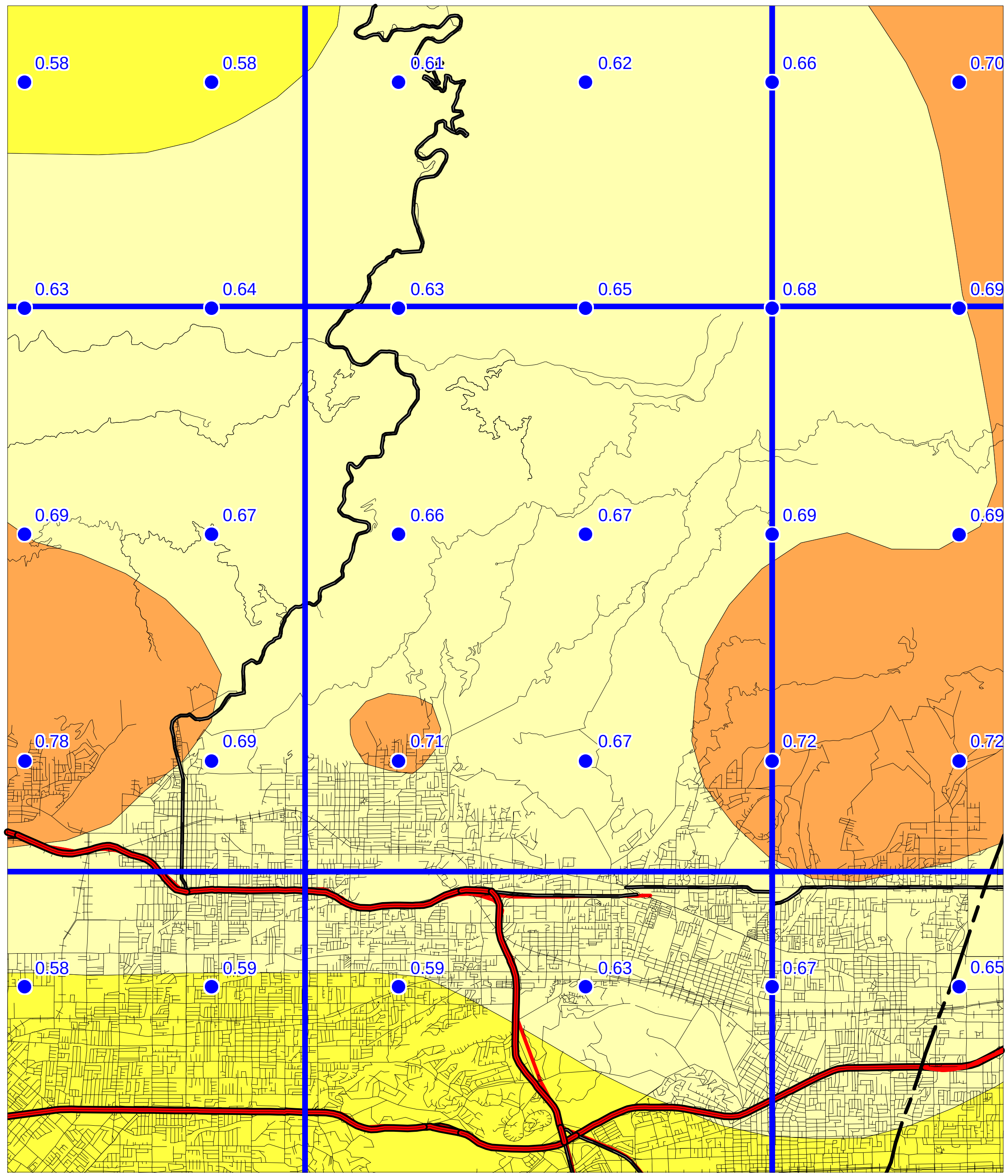
Department of Conservation
Division of Mines and Geology

Figure 3.2

GLENDORA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)
1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen

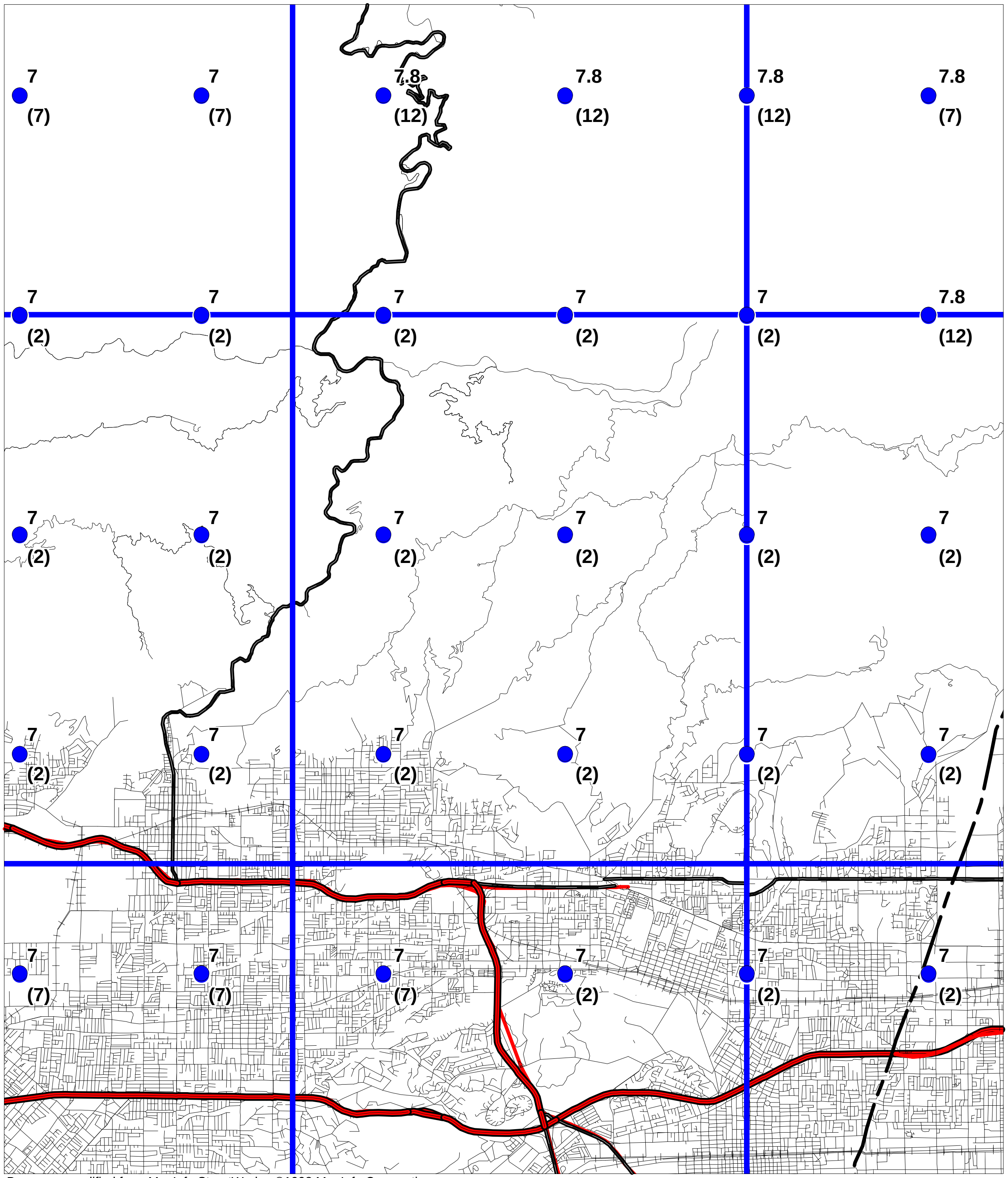
Figure 3.4. Glendora 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration—Predominant earthquake.

GLENDORA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.4

1. and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not previously been recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (California State Mining and Geology Board, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

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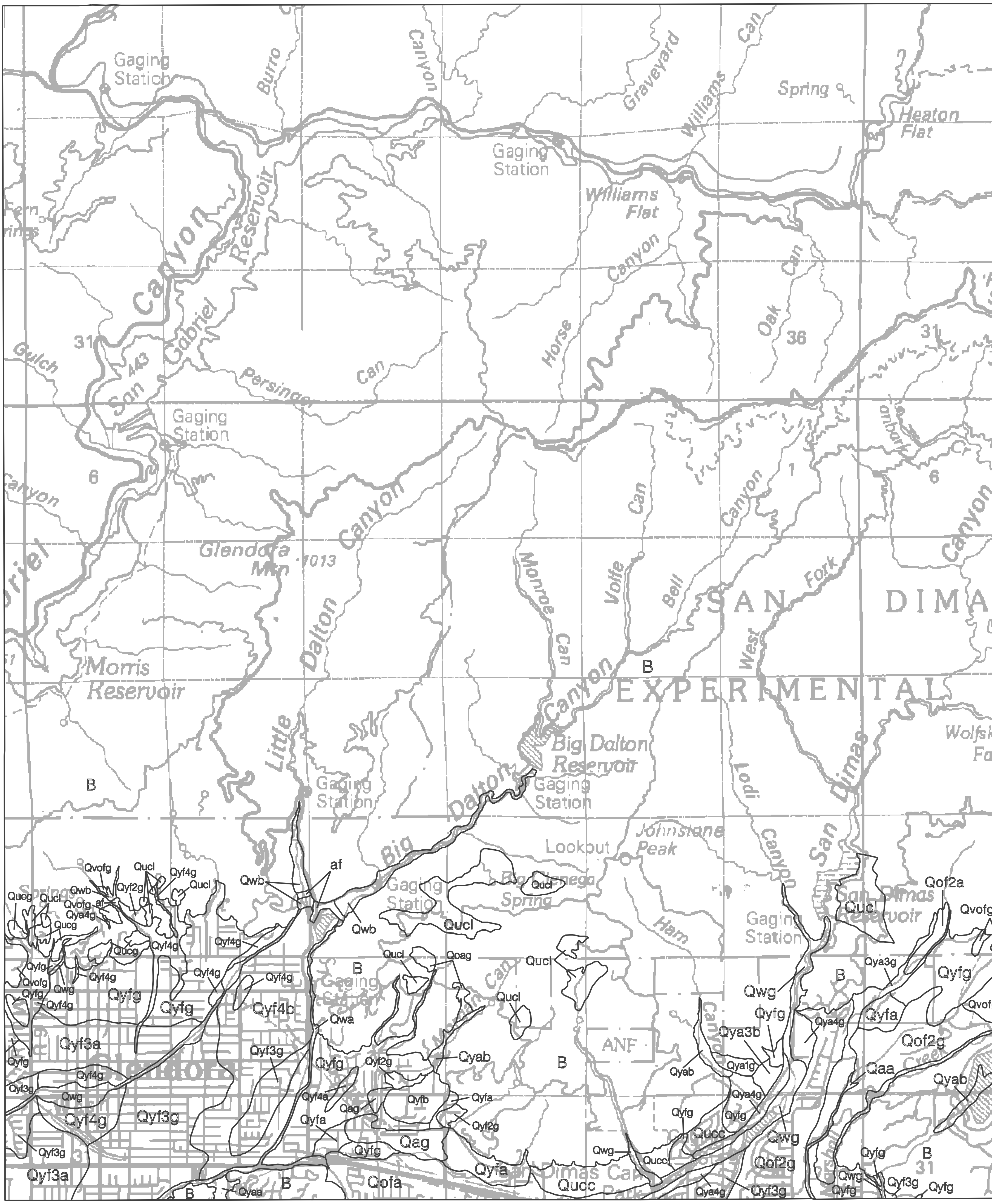


Base map enlarged from U.S.G.S. 30 x 60–minute series

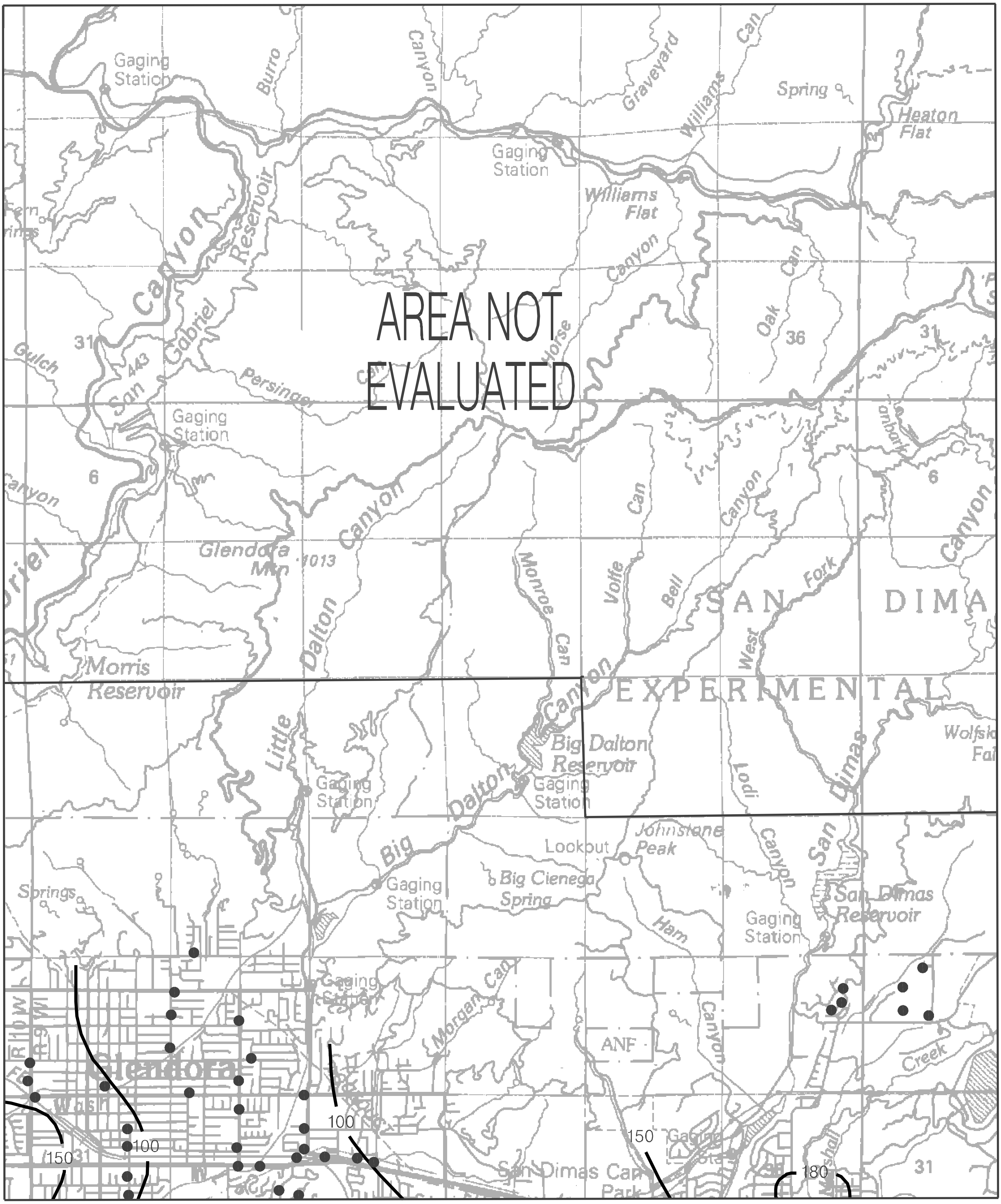
Plate 1.1 Quaternary Geologic Map of the Glendora Quadrangle.

See Geologic Conditions section in report for descriptions of the units.

B = Pre–Quaternary bedrock.

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

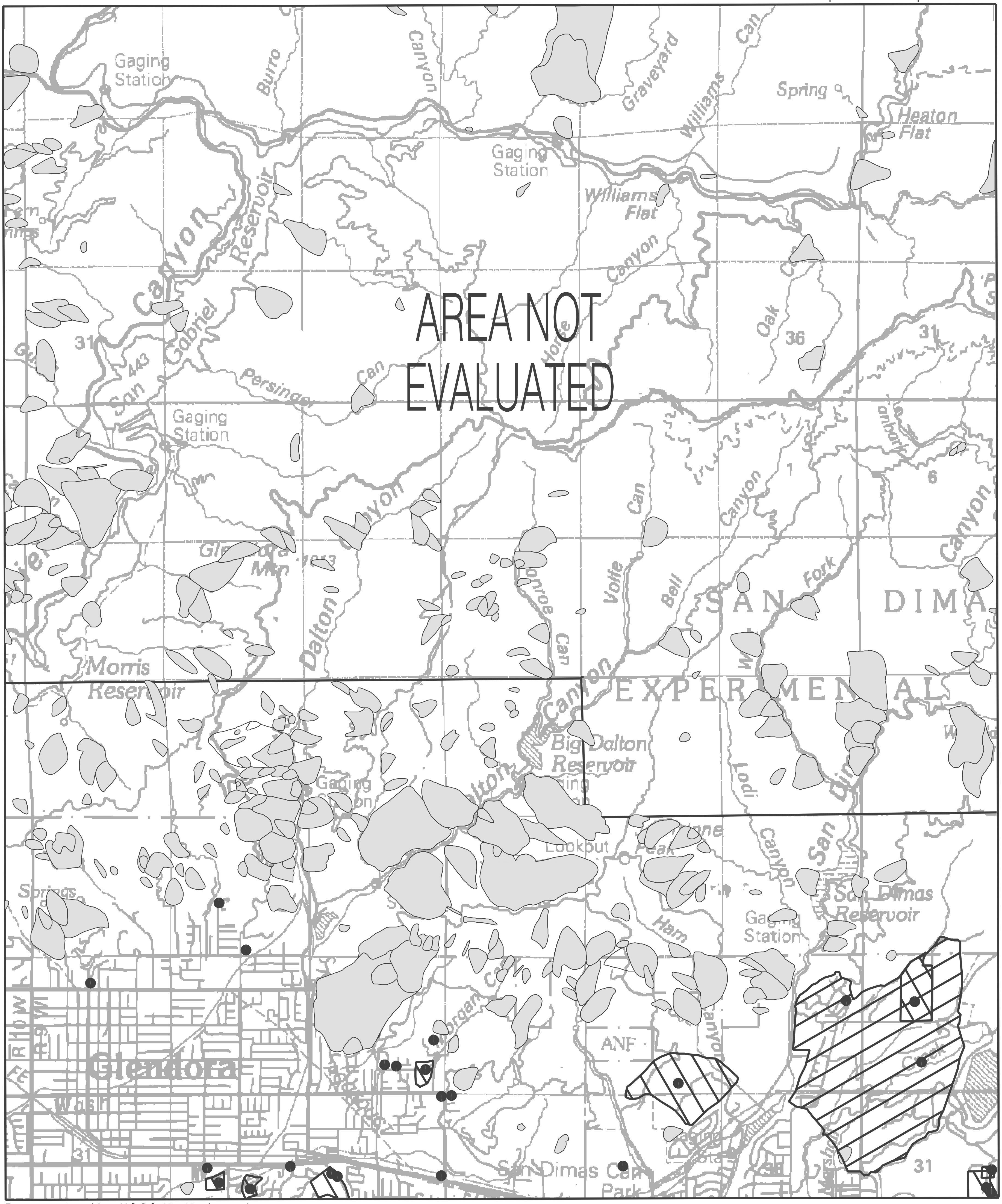
Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Glendora Quadrangle.

● Borehole Site

30 Depth to ground water in feet

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 2.1 Landslide inventory, Shear Test Sample Locations, and Areas of Significant Grading, Mint Canyon Quadrangle.

● shear test sample location — landslide — areas of significant grading — tract report with multiple borings

ONE MILE

SCALE